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SOME OBSERVATIONS CONCERNING WOOD PIPE[1]

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HISTORY

As a conduit for water, wood pipe was used before the Christian era, and up to within two centuries ago, with the exception of lead, it was the only pipe in existence, except for large gravity conduits and aqueducts where masonry was in use. The first wood pipes used consisted of logs with holes bored through the center, the joints being made by shaving one end to a taper to fit the inside of the next length. This type with modifications remained in use for centuries in European countries. London had several hundred miles of wood pipe, 400 miles of which were laid in 1613. It was its sole means of water supply for over two hundred years, and portions of the original lines unearthed in modern excavations have been found sound and solid. These pipes were "elm pump logs." It is stated that in 1862 some of these pipes were taken up after being in the ground 249 years, and found to be in good condition. Constantinople received its entire water supply through bored wood pipe for more than two centuries, and part of the city is still supplied in the same way. Philadelphia, New York, Boston and many other cities obtained their first supply of water through wood pipe, and some still retain this original wood pipe. In 1798 Aaron Burr organized the Manhattan Company and supplied residents in New York City with water through wooden pipes. The Water Company continued the service until 1842. Within recent years some of these old pipes have been dug out, and it is stated that the wood was found in a perfect state of preservation. In Philadelphia the wooden pipes were laid in 1799. They were made of oak logs 3 feet in diameter, rough dressed on the outside and with a bore ranging from 6 to 12 inches. Some consisted of spruce or pine logs bored out, mortise and tenon at ends with wrought iron bands fastened around each end. A great deal of it was in continuous use until 1844. Many of these pipes when dug up were found to be in good condition, although the iron bands which were used to make the sections were rusted away.

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Boston, Massachusetts, built the first public water supply in America in 1652. The mains consisted of wood pipe, which were largely replaced with wood again in 1796. They were mostly taken up in 1848 and cast iron pipe susbstituted.

The above facts simply corroborate what is common knowledge, that wood pipe, constantly buried in the ground or kept saturated with water, has an indefinitely long life. It is true also that wood in a dry place is practically indestructible; on the other hand when the unpainted or uncoated material is subjected to alternate wet and dry and exposed to the air, the best wood obtainable will seldom last longer than twelve years, but a live tree of the same material will last several hundred years. All these facts show that the elements of destruction can be warded off and overcome.

Nearly seventy years ago a new method was developed for making wood pipe. This consisted of sawing the wood into narrow wedge shaped staves and forming them into a hollow cylinder, the longitudinal joints being radial. One end of the cylinder was formed into a tenon; the other end into a mortise, and so tapered that the sections of pipe so formed could be driven together making a continuous pipe. The staves were forced together and kept in place with iron wire or flat bands wound around the surface and frequently stapled or nailed in place.

A modification of this form omitted the mortise and tenon but provides a short constructed sleeve to form the transverse joint.

Still a later modification was the continuous wood stave pipe where dove-tailed staves of random lengths were formed into a pipe in the field and held together by hoops, or rods, having screw connections. The end joints of the staves were made tight by metal strips fitted into a sawed slit. This is known as the continuous wood stave pipe, and is very popular in large sizes, especially in the western country where redwood and Oregon fir woods are used. All these have almost completely superseded the bored lugs of the ancients.

The wood pipe industry is much more extensive than is commonly realized, and there are a number of concerns who have been for many years doing a large business. It would probably be conservative to say that there are installed during each year at least five hundred miles of wood pipe in various parts of the United States by the various companies engaged in the business. They are made in all sizes from 4-inch to 60-inch, and in some cases for large conduits and flumes as high as 12 or 13 feet in diameter and for pressures from zero to 150 pounds.

It may be stated in passing that nearly all the prominent wood pipe manufacturers are equipped for making either continuous or machine banded pipe, although some of the western companies make a specialty of large diameter redwood and fir continuous wood stave pipe. Western redwood and fir trees grow to large sizes and it is easy to obtain from them staves of any length, free from knots or other imperfections, which is impossible with the commonly used eastern pines and other woods.

For some years back the wood pipe companies have realized that in many situations the life of the wood could be very materially increased by creosoting, and I learn from some of the companies that about half of their business consists in creosoted pipe, and they say that this will give an average of double life of the untreated wood. However, in the majority of situations the life of wood pipe is dependent upon the life of the steel rods or bands.

The two main features which make the use of wood pipe attractive are low initial cost and constantly high carrying capacity.

A fair comparison of the cost installed of wood and cast iron pipe based on 65 pounds working pressure and New York delivery is as follows:

TABLE 1

NOMINAL PIPE DIAMETER	MACHINE BANDED WOOD PIPE		CONTINUOUS WOOD PIPE	CAST IRON PIPE AT $44 PER TON FOB NEW YORK
	Pine	Redwood	Redwood	
inches	*per foot*	*per foot*	*per foot*	*per foot*
6	$0.96			$1.26
12	1.49			2.69
20	2.29	$3.70	$3.4	5.21
24	2.89	4.84	4.19	6.71
30	4.13		5.27	9.13
36			6.35	12.02
48			9.50	18.90

All these prices are based on hauling taken at $2 per ton and trenching taken at the same price for the same size pipe. If we consider 20 and 24-inch sizes, we have:

TABLE 2

ITEMS	20-INCH	24-INCH
Machine banded pine	$2.69	$2.89
Machine banded fir	3.27	4.31
Machine banded redwood	3.70	4.84
Continuous redwood	3.43	4.19
Continuous fir	2.92	3.58

In the above prices, trenching is taken per lineal foot as follows:

6-INCH	12-INCH	20-INCH	24-INCH	30-INCH	36-INCH	48-INCH
$0.37	$0.52	0.78	$1.00	$1.15	$1.40	$2.00

The following weights of pipe are taken in pounds per lineal feet:

TABLE 3

ITEMS	6-INCH	12-INCH	20-INCH	24-INCH	30-INCH	36-INCH	48-INCH
Machine banded pine	15	22	38	49	85		
Machine banded fir			37	40			
Continuous redwood			35	44	60	76	115
Continuous fir			38	48	66	83	125
Cast Iron	31	76	160	210	300	407	660

For the design of wood pipe two main points must be considered. The iron bands must be strong enough to resist the internal pressure and their compression against the wood must not be sufficient to indent the wood injuriously. In practice it is found that where round rods are used, an average bearing of half the diameter of the rod gives good results. With the softest woods it is generally assumed that it is not necessary to figure lower than about 500 pounds per square inch. The western manufacturers usually take 750 pounds per square inch, and for Douglas fir a considerably higher figure.

The Government Forest Service in a series of tests conducted at Madison, Wisconsin, found that a rod half inch in diameter would sink into a redwood stave under a pressure of 545 pounds per square inch. The measure of the crushing width was equal to half the diameter of the rod.

From this test it might be inferred that the practice of the redwood pipe manufacturers is unsafe. As this has been in vogue for some thirty odd years with success, there must be some good reason why failure does not take place, and that is probably due to the fact that the rod sinks into the wood until the bearing pressure per unit of area is reduced to an amount that will no longer crush the wood. For instance, if the bearing area were increased to the diameter of the rod instead of one-half the diameter, the pressure per square inch would be correspondingly reduced one-half. Even when the rod bears on one-half the diameter, there is some indentation of the wood, and the chances are that the full section of the stave is not permanently injured by this indentation.

In view of the test above noted, however, it would be conservative practice to use a figure of 500 pounds per square inch instead of 750, and this would apply to such soft woods as redwood, white pine and Norway pine. For such woods as Oregon fir, yellow pine, spruce, chestnut, etc., a value of 750 pounds would be conservative. For such woods as ash, oak, elm, beech, long leaf heart pine, birch, etc., a considerably higher figure should be used; but the only woods that have been considered as generally suitable for wood pipe have been redwood, fir, white pine and Norway pine, and sometimes cypress.

Assuming the pressure on the inside of the pipe is of uniform intensity, the pressure exerted against an iron band is exactly equal to the pressure on the internal surface of the pipe between the centers of two bands, so for the case of a round rod, if we take the bearing area as equal to one-half its diameter, the formula for bearing pressure is easily deduced as follows:

$$L = \frac{Bd\ (D + 2T)}{2\,Dp} \tag{1}$$

in which L = spacing of rods between centers in inches.
D = internal diameter of pipe in inches.
p = pressure in pounds per square inch.
d = diameter of rod in inches.
T = thickness of the wood shell.
B = pessure in pounds per square inch on the wood.

If we consider flat bands, the formula becomes:

$$L = \frac{Bb\ (D + 2T)}{pD} \tag{2}$$

In which b = width of the band in inches, and all the other terms are the same as before. For the strength of the steel, the formulae are:

$$L = \frac{2\,a\,S}{pD} \tag{3}$$

or for the flat band:

$$L = \frac{2\,b\,t\,S}{pD} \tag{4}$$

in which a = the minmum sectional area of the steel band.
S = working strength of the steel in pounds per square inch.
p = the pressure in the pipe in pounds per square inch.
D = the diameter of the pipe in inches.
b = the width of the band in inches.
t = the thickness of the band in inches.

For wood pipe design S is usually taken between the limits of 12,500 and 22,000; 17,500 pounds per square inch being about an average figure.

It is seen from the above formulae that for small sizes of pipe where round rods are used, the spacing must be much closer than indicated by the formulae for steel strength, otherwise, the pressure on the wood would be excessive.

Where the strength of the steel is the criterion, the best practice for round rods is to upset the ends so that the base of the thread has the same area as the full section of the round rod, but it is very common, however, to use standard threads.

Probably the most usual diameter of rod is $\frac{1}{2}$ inch.

These remarks apply to what are known as independent rods and lugs, which are universally used with continuous pipe and are sometimes used with machine made pipe. The most common practice, however, with machine banded pipe is to use flat bands or wire, the winding being done in the factory with a machine that secures a uniform tension on the wire or band. The following table of round rods is useful in wooden pipe practice:

TABLE 4

DIAMETER OF ROUND ROD	AREA IN SQUARE INCHES	AREA AT BASE OF STANDARD THREAD	PERCENTAGE OF STRENGTH AT FULL SECTION
inch	*square inches*		
$\frac{1}{4}$	0.049	0.027	55
$\frac{1}{2}$	0.196	0.126	64
$\frac{9}{16}$	0.249	0.162	65
$\frac{5}{8}$	0.307	0.202	66
$\frac{3}{4}$	0.442	0.302	68

If we take the usual practice of wood pipe manufacturers and use a bearing pressure of 750 pounds per square inch on the wood, and use $\frac{1}{2}$-inch rods with standard threads and allowing a working stress of 17,500 pounds per square inch in steel, we find that for all sizes of pipe up to 20-inch inclusive, the spacing should be determined by formula 1, and for sizes above 20-inch the spacing should be based on the formula 3.

For pipe wound with round wire, if we assume that the spacing would be such as to produce a given pressure on the wood and a given tension in the iron, we may equate formulae 1 and 3, and obtain formula 5:

$$d = \frac{B\ (D+2T)}{\pi S} \tag{5}$$

in which d = diameter of the wire.

B = pressure per square inch against the wood.

S = stress in steel wire per square inch.

D = diameter of the pipe.

T = thickness of the pipe, all in inches: 2 inches for 24-inch and under, and 3 inches for 30-inch and above.

If we should assume S = 15,000 pounds per square inch, and

B = 750 and 500 pounds per square inch respectively,

the size wires would correspond to the following table:

TABLE 5

INSIDE DIAMETER OF PIPE	DIAMETER OF WIRE FOR 750 POUNDS PRESSURE ON THE WOOD	NEAREST CORRESPONDING B. W. G.	DIAMETER OF WIRE FOR 500 POUNDS PRESSURE ON THE WOOD	NEAREST CORRESPONDING B. W. G.
inches				
4	0.128	10	0.085	14
6	0.159	8	0.106	12
8	0.191	6	0.127	10
10	0.223	5	0.148	9
12	0.255	3	0.170	7
14	0.287	2	0.191	6
16	0.319		0.212	5
18	0.350		0.233	4
20	0.382		0.255	3
24	0.446		0.297	1
30	0.573		0.382	

The spacing of these wires would be the same whether formula 1 or 3 were used.

For independent rods and lugs we have to take the strength of the steel rod according to the sectional ara at the base of the thread. The following table gives the spacing of round rods, as calculated

TABLE 6

DIAMETER OF PIPE	DIAMETER OF ROD	PRESSURE IN POUNDS PER SQ. INCH					
		25	50	75	100	125	150
		Spacing between centers in inches					
inches							
4	No. 10 B. W. G.	4.02	2.01	1.34	1.01	0.80	0.67
6	No. 8 B. W. G.	4.13	2.06	1.37	1.03	0.82	0.69
8	No. 6 B. W. G.	4.57	2.28	1.52	1.14	0.91	0.76
10	No. 5 B. W. G.	4.62	2.31	1.54	1.15	0.92	0.77
12	No. 3 B. W. G.	5.18	2.59	1.73	1.29	1.04	0.86
14	No. 2 B. W. G.	5.48	2.74	1.82	1.37	1.09	0.91
16	½ inch rod, standard thread	9.45	4.72	3.15	2.36	1.89	1.57
18	½ inch rod, standard thread	8.40	4.20	2.80	2.10	1.68	1.40
20	½ inch rod, standard thread	7.56	3.78	2.52	1.89	1.51	1.26
24	½ inch rod, standard thread	6.30	3.15	2.10	1.57	1.26	1.05
30	½ inch rod, upset thread	7.83	3.92	2.61	1.96	1.57	1.31
36	⅝ inch rod, upset thread	10.23	5.12	3.41	2.56	2.05	1.71
40	⅝ inch rod, upset thread	9.20	4.60	3.07	2.30	1.84	1.53
48	⅝ inch rod, upset thread	7.67	3.84	2.56	1.92	1.54	1.28

from the above formulae, and based on the practice of the eastern manufacturers, the working strength of the steel being taken at 15,000 pounds per square inch and the pressure on the wood not to exceed 750 pounds per square inch. For sizes from 4-inch to 24-inch inclusive, the thickness of the shell of the pipe is assumed to be 2 inches and for sizes above 24-inch, 3 inches. For sizes from 4-inch to 14-inch inclusive it is assumed that the pipe is spirally wound with wire, and the spacing is computed by formula 1. From 16-to 24-inch, ½-inch rods with standard threads are used, and the spacing is computed by formula 3; for 30-inch pipe, ½-inch rods with upset ends; and for 36, 40- and 48-inch pipe, ⅝-inch rods with upset ends.

TABLE 7

NOMINAL DIAMETER OF PIPE	NUMBER B. W. G.	DIAMETER OF WIRE OR ROD	PRESSURE IN POUNDS PER SQUARE INCH					
			25	50	75	100	125	150
inches		*inches*						
4	13	0.095	1.90	0.95	0.63	0.47	0.38	0.31
6	12	0.109	1.82	0.90	0.60	0.45	0.36	0.30
8	10	0.134	2.01	1.00	0.67	0.50	0.40	0.33
10	9	0.148	2.07	1.03	0.69	0.51	0.41	0.34
12	7	0.180	2.40	1.20	0.80	0.60	0.48	0.40
14	6	0.203	2.61	1.30	0.87	0.65	0.52	0.43
16	5	0.220	2.75	1.37	0.91	0.68	0.55	0.45
18	4	0.238	2.91	1.45	0.97	0.72	0.58	0.48
20	3	0.259	3.11	1.55	1.03	0.77	0.62	0.51
24	1	0.300	3.50	1.75	1.16	0.87	0.70	0.58
30	Independent rods	0.500	6.00	3.00	2.00	1.50	1.20	1.00
36	Independent rods	0.500	5.84	2.92	1.94	1.46	1.16	0.97
40	Independent rods	0.625	7.18	3.59	2.39	1.79	1.43	1.19
48	Independent rods	0.625	7.02	3.52	2.34	1.76	1.40	1.17

Table 7 gives the spacing on the basis of 500 pounds per square inch pressure on the wood, the stresses in the steel not exceeding 15,000 pounds per square inch. For all sizes from 4- to 24-inch the thickness of the wood is assumed to be 2 inches, and from 30- to 48-inch inclusive, 3 inches. For sizes up to 24-inch, the round spirally wound wire is assumed to be used of the gauges shown, and from 30- to 48-inch inclusive independent rods and lugs with threads upset to give the full section of the rod. The spacing is calculated by formula 1, which applies for the entire table. For round rods this table represents the most conservative practice.

For flat bands machine spirally wound, on the basis of a working strength of 15,000 pounds per square inch for the steel and bands 1½ inches wide, the following table of spacing in inches between center of bands will apply:

TABLE 8

	SIZES OF PIPE											
	4-inch	6-inch	8-inch	10-inch	12-inch	14-inch	16-inch	18-inch	20-inch	24-inch	30-inch	36-inch
25 pounds pressure												
B. W. G.	18	18	18	18	18	18	18	14	14	14	14	14
Spacing	11	11	11	8.81	7.35	6.30	5.51	8.30	7.47	6.22	4.98	4.15
50 pounds pressure												
B. W. G.	18	18	18	18	18	18	18	14	14	14	14	14
Spacing	11	7.35	5.52	4.41	3.68	3.15	2.75	4.15	3.74	3.11	2.49	2.07
75 pounds pressure												
B. W. G.	18	18	14	14	14	14	14	14	14	14	14	10
Spacing	7.34	4.90	6.22	4.98	4.15	3.55	3.11	2.76	2.49	2.07	1.66	2.23
100 pounds pressure												
B. W. G.	18	14	14	14	14	14	14	14	14	14	10	10
Spacing	5.51	6.22	4.66	3.74	3.10	2.66	2.33	2.07	1.86	1.55	2.01	1.67
125 pounds pressure												
B. W. G.	18	14	14	14	14	14	14	14	12	10	10	8
Spacing	4.41	4.97	3.73	2.99	2.48	2.13	1.87	1.66	1.96	2.01	1.60	1.65
150 pounds pressure												
B. W. G.	18	14	14	14	14	14	14	12	12	10	8	6
Spacing	3.67	4.15	3.11	2.49	2.07	1.78	1.55	1.81	1.63	1.68	1.65	1.69

It is seen that with flat bands for any practical spacing, the pressure on the wood is less than 500 pounds per square inch, and therefore the question of indentation of the wood is eliminated. For that reason for continuous wood stave and machine made pipe, where independent rods and lugs are specified, it has been proposed to substitue for the round rods flat iron of equivalent section, the ends being forged into the required shapes for connecting with the lugs. The usual arrangement consists of a thread 5 inches long on one end and a buttonhead on the other. This with the single lugs are much more convenient to handle in the field than the double lugs and double threaded rods.

In the tables, the shell of the pipe has been taken as 2 inches thick for all sizes up to 24 inches inclusive and 3 inches thick for sizes above 24-inch in accordance with the practice of the eastern manufacturers, but the western companies use thinner staves for redwood and fir, the thickness ranging from about 1 inch for 4-inch pipe to 1⅝ inch for 36-inch pipe.

While the above sizes of rods and bands and the spacing may not agree with the practice of the various manufacturers, it is given so as to afford the engineer a check on their proposals.

Machine spirally wire or band wound pipe has theoretical advantages over independent rods and lugs, which are put on and tightened in the field, because the tension produced in the factory is automatically uniform, and for the further reason that the pipe can be covered with a protective coating, which will add materially to the life of the banding. In case of leakage along the longitudinal seams, however, the independent rods and lugs can be tightened in the field. With the pipe made up in the factory the usual method of stopping the leaks is to drive wooden wedges between the band and the pipe, and this is usually done at the horizontal center, and affords a very quick and effective method for stopping this kind of leakage when it is not excessive.

There is some difference of opinion as to whether for machine banded pipe, wire wound is preferable to band wound pipe. Each of these types has its advantages. The wire winding presents the minimum surface to corrosion, while the flat bands present the maximum area of corrosion. On the other hand the flat band subjects the pipe to the least pressure on the wood and the round rod to the greatest. The flat band can be coated in a more effective manner than the round rod and where the life of the steel is likely to depend on the efficiency of the coating the flat band seems to offer the best proposition. In the majority of cases wood will outlast the steel winding, be it either round or flat.

WATER HAMMER

It must be understood that wood pipe is as much subject to water hammer as is any other, so in selecting the pressures due consideration must be given to the possibility of material increase due to water hammer. There are many causes for water hammer. When the water in a long pipe is flowing at a high velocity, if a gate is shut down quickly, the velocity is reduced, and the inertia of the moving column of water causes increased pressure. If the line is flowing by gravity, and a heavy draft takes place in a low portion of the line, the discharge may be greater than the upper flatter portion of the pipe line is able to supply, in which case the column of water is likely to part, leaving a partial vacuum in a portion of the pipe line. This causes an acceleration of the moving column, so that if the draft is suddenly reduced the two columns will come together at an indefinitely high velocity, causing serious water hammer. The practical remedy for this situation is to use surge tanks or their equivalent.

The fundamental formula for water hammer is:

$$p = \frac{0.027\,LV}{T} \tag{6}$$

in which L = length of the pipe in feet.
V = velocity (ft. per second).
T = the time of extinguishing said velocity (seconds).
p = pounds pressure per square inch in excess of the hydrostatic pressure.

The pressure will reach a certain limit which depends on the length of pipe, the diameter, thickness and the quality of material.

To deduce a rational formula for water hammer for wood pipe to apply to a case when the velocity of water is stopped suddenly is a complicated process and at best uncertain. This branch of hydraulics, even for the simplest case, is more or less involved, and where we have the combined effect of the elasticity of the wood, of the steel bands and of the water, the complication is immeasurably increased. However, strict accuracy is not essential in any case, because the causes of water hammer are subject to wide variation. The simplest formula is:

$$p = V\left(\frac{3970\,E\,t}{Et + 294{,}000\,D}\right)^{\frac{1}{2}} \tag{7}$$

in which E = the coefficient of elasticity of the band.
t = thickness of the material of the shell, i.e., the band.
D = diameter of the pipe in inches.

V = velocity in feet per second suddenly stopped.
p = pressure in pounds per square inch due to water hammer for instantaneous extinguishment of velocity.
294,000 = coefficient of elasticity of water.

For steel bands having a coefficient of elasticity of 28,000,000 this formula reduces to

$$p = V\left(\frac{378{,}000\,t}{95\,t + D}\right)^{\frac{1}{2}} \tag{8}$$

As an example assume the pipe to be 24 inches, 10,000 feet long, thickness of band $\frac{1}{8}$ inch, velocity 5 feet per second. If the velocity is suddenly stopped, p would equal 181 pounds per square inch. By applying the fundamental formula it is seen that if the velocity is stopped in 7.4 seconds, or less, the result would be the same as if it were stopped instantly.

Incidentally it will be noted that the effect of sudden stopping is independent of the length of the pipe, and as the water hammer can never be greater than that due to sudden closing, we have a certain amount of insurance against the effect of closing valves too quickly. This insurance, however, is more imaginary than real, because in both formulae the pressure due to water hammer is proportional to the velocity reduced, and there are many conditions which will produce accelerating and unduly high velocities, as for instance, a high rate of draft at a low portion of a pipe line, the sudden release of an accumulation of air, or anything that will produce a temporary vacuum in a portion of the line. Any one of these conditions will cause an acceleration, and water will run down the incline according to the law of falling bodies, and develop an indefinitely high velocity, which is suddenly extinguished when it meets the still column of water ahead.

The practical aspect of this matter is that everything possible should be done to prevent water hammer. The most effective remedies are in gravity lines to divide the total length into short sections by leveling reservoirs or surge tanks, and to provide a good design of automatic air valve on all the summits. For pumping where the line is long, water should be pumped into an elevated reservoir or standpipe close to the pumping station, and if this is impracticable, large air chambers should be used, and means for charging them with air. Where the pumps are centrifugal and run by electricity, the power occasionally goes off suddenly. The column of water, however, continues on some distance, causing a reduction of pressure at the pumps often below the atmosphere. The water column will then recede by gravity until it reaches the check valve at a high velocity, and as for this situation air chambers are not usually provided, a serious water hammer takes place, which is the cause of a great many broken discharge mains. A simple remedy is to connect the discharge main outside of the check with a tank kept full of water and between the tank and the discharge main should be a check valve opening outwardly. The main will then be kept full of water, and as soon as the velocity is reduced to zero the column of water will not recede and no water hammer will take place.

DISCHARGING CAPACITY OF WOOD PIPE

Much has been written concerning the formula for flow in wood pipe. The writer is of the opinion that the formulae such as Hazen and Williams, Chezy and others, for new cast iron pipe are applicable to wood pipe of any age. It is quite probable that the flow through a perfectly new straight cast iron pipe would be slightly greater than for wood pipe of some age, due to the fact that the interior surface of the wood is more liable to have attached to it a film, or scum, which slightly reduces the flow.

The difference, however, is not very material, but for many situations the reduction in flow in cast iron, even in a very few years, makes the discharging capacity of the wood pipe much superior. For soft mountain waters and those of the coast, where the color is high, cast iron pipe is likely to reduce within ten years, more than 20 per cent of its original capacity, due to tuberculation. Wood pipe is entirely free of this difficulty.

The writer made very careful and repeated tests of the flow through ten miles of 24-inch wood pipe where the velocity was about 4 feet per second, and found the coefficient in Chezy's formula to be 111. In this case the pipe was not perfectly round. If it had been round the flow would have increased. This phase of wood pipe operation is very important. Where the pipe is in a trench with a considerable fill over it and the pressure low, the pipe will assume an oblate form, the vertical diameter being materially less than the horizontal. The effect is to reduce the hydraulic mean radius and consequently the flow. When the pressure is increased materially, the pipe will become more nearly circular in form, and the coefficient will correspondingly increase. This is one reason why a great deal of trouble is experienced with leakage in wooden pipes. If it is subject to low pressure when installed and then after some years the pressure is increased materially, leakage is apt to develop along the staves as well as in the joints. The remedy is to operate constantly this class of pipe under fairly uniform pressures.

SHORT WOOD PIPES

There are many wood pipes in service for flumes of short lengths, and an engineer is often at a loss to know how to calculate the flow in a very short pipe. The main point is to take account of the various losses of head that occur. The following formulae will apply to any pipe, be it short or long:

$$Q = \frac{0.3927\, D^{\frac{5}{2}}\, H^{\frac{1}{2}}}{\sqrt{\frac{L}{c^2} + 0.00582\, D}} \tag{9}$$

in which Q = cubic feet per second.
D = diameter in feet.
H = total head in feet.
L = length in feet.
c = Chezy's coefficient.

Where the flow is in gallons per 24 hours, and the diameter of the pipe is in inches, the formula becomes:

$$q = \frac{508.9\, d^{\frac{5}{2}}\, H^{\frac{1}{2}}}{\sqrt{\frac{L}{c^2} + 0.000485\, d}} \tag{10}$$

in which q = gallons per 24 hours.
d = diameter of the pipe in inches.

These formulae allow for velocity head and entrance head equal to half the velocity head.

It will be noted that No. 9 is a modification of Chezy's formula, and if this be reduced to velocity and the head taken as feet per thousand, and the pipe is indefinitely long, the formula reduces to:

$$V = \frac{C\sqrt{Dh}}{63.2} \tag{10½}$$

in which D = diameter in feet
h = head in feet per thousand

Nearly all the investigators of the flow through pipe have concluded that the Chezy formula cannot be used with accuracy unless the value of C is changed to correspond to different diameters of pipe.

Scobey, Hazen and Williams, Moritz and others have made a very careful study of the flow of water in pipes, and Scobey's results and Hazen and Williams' correspond very closely. Taking Scobey's results on the basis of a loss due to friction of one foot per thousand, we have

for a 12 foot pipe—$C = 148$
for an 8 foot pipe—$C = 127$
for a 6 foot pipe—$C = 134$
for a 1 foot pipe—$C = 118$

and the formula of Hazen and Williams would give practically the same results although slightly smaller, but it is more convenient to use the Chezy formula even if we give to C different values corresponding to the diameters of the pipes, because the formula can be reduced to such a form as will allow for velocity and entrance heads, which is not practicable with the other formulae.

It is generally supposed that all the losses of head except that of friction vary with the square of the velocity. The importance of having a formula that is applicable for any length of pipe is shown by the fact that where only friction is taken into account, we would have a velocity in a 12-foot pipe of 6.05 feet per second while if the pipe were 1,000 feet long the true velocity would be only 4.4 feet per second.

ECONOMICAL COMPARISON OF WOOD AND CAST IRON PIPE

For all ordinary sizes of pipe it is generally recognized that the present standard is cast iron pipe. For water purposes there is more cast iron pipe used than all other pipes combined, the reason being that cast iron pipe can be made absolutely tight under all circumstances and will remain so under all variations of pressure. For very large sizes, however, it is too costly as compared with wood or steel, and under many situations the reduction in capacity due to tuberculation is so serious that engineers will prefer a reinforced concrete pipe or wood pipe.

Undoubtedly in regard to extensive use, wood pipe comes next to cast iron. It may be conservatively stated that cast iron pipe will last 100 years, when under average cases, it may be stated that a wood pipe would not last more than 25 years. There are many modern wood pipes that have been giving good service much longer than 25 years, but when we compare with cast iron it is best to assume the short life for the wood pipe. Therefore, we may say that the life of a cast iron pipe is 100 years and that of a wood pipe 25 years.

As an example, let us take 24-inch continuous redwood pipe and assume a life of 25 years. Say the wood pipe will have to be renewed four times in a hundred years and cast iron pipe only once at the end of 100 years. Let us take the average discharging capacity for the wood pipe as 20 per cent greater than that of cast iron. The initial cost of 10,000 feet of wood pipe for 65 pounds working pressure is $41,900. The same amount of cast iron pipe would cost $67,600. To obtain an increase of capacity of the cast iron pipe to make it equivalent to that of wood pipe a larger size would have to be put in If a 30-inch pipe is used, the increase of capacity would be 75 per cent,

TABLE 9

	WOOD	CAST IRON
Initial cost of 24 inch diameter pipe	$41, 900	$67, 600
Increase in cost of cast iron pipe to obtain 20 per cent increased capacity		6, 450
Initial cost for equal average capacity	$41, 900	$74, 050
Annual charges		
Wood Pipe, Repairs 1 per cent, taxes 0.6 per cent	$670	
Cast Iron Pipe, Repairs 0.25 per cent, taxes 0.6 per cent		$630
Present Worth of $41,900 at 5 per cent for renewal in 25 years	$12, 373	
Present Worth of $41,900 at 5 per cent for renewal again in 50 years	3, 654	
Present Worth of $41,900 at 5 per cent for renewal again in 75 years	1, 079	
Present Worth of $41,900 at 5 per cent for renewal again in 100 years	319	
Present Worth of $670 per year for 100 years at 5 per cent	13, 400	
Present Worth of $630 per year for 100 years at 5 per cent		12, 600
Initial cost for equal average capacity	41, 900	74, 050
Total present worths	$72, 725	$86, 650

and the increased cost would be \$24,200, so therefore to get an increased capacity of 20 per cent, in the same ratio, the increased cost of the cast iron pipe would be $\frac{20}{75}$ of \$24,200, or \$6,450, or a total initial cost of \$74,050. We may take the cost of repairs of the wood pipe as 1 per cent per annum and the taxes as 0.6 of 1 per cent, and for the cast iron pipe we may take the annual repairs as $\frac{1}{4}$ of 1 per cent and the taxes as 0.6 of 1 per cent as before, so that the annual charge for wood pipe would be \$670 and for cast iron pipe \$630. This is all shown in table 9.

The saving of putting in wood pipe based on present worths would therefore be \$13,925, which is nearly 19 per cent of the initial cost of the cast iron pipe.

If we should take machine banded eastern pine wood, the initial cost would be \$28,900 as against \$41,900, and the present worth figures obtained for wood pipe by the same method would be \$50,125 and for the cast iron pipe \$86,650, or a saving of \$36,525 in favor of the wood pipe, which is 50 per cent of the initial cost of the cast iron pipe. For larger sizes of pipe the difference becomes greater.

For 12-inch machine banded eastern pine pipe the initial cost would be \$14,900 for the wood pipe and \$26,900 for the cast iron pipe, but to obtain 20 per cent increased capacity for the cast iron pipe by the same method as before would cost \$2,170, or a total initial cost of the cast iron pipe of \$29,070. The annual cost of repairs and taxes for the wood pipe would be \$238, and for the cast iron pipe \$247, so that the present worth of the total cost of the wood pipe would be \$25,847, and of the cast iron pipe \$34,027, or a saving of \$8,180, which is about 28 per cent of the initial cost of the cast iron pipe.

When a financial comparison on a rational basis shows such a material advantage of wood over cast iron pipe, the question naturally arises, why is cast iron so universally preferred by most of the leading engineers? It is, no doubt, because there have been so many unfortunate experiences with wood pipe. Successful installations cause only casual comment and consideration, but when a failure takes place it has the same effect on engineering sentiment as does a moral scandal on that of the public; successes are forgotten and the failures vividly remembered.

Then again, cast iron pipe is suitable for nearly all situations and conditions of operation under the widest range of pressure and flow, and even in the circumstances of distribution mains where the carrying capacity is reduced as much as 75 per cent, its reputation for reliability and ruggedness is not destroyed; the owners comforting themselves, where they happen to know about it, with the feeling that they can always restore the capacity by cleaning. On the other hand, there are frequently conditions that would give no trouble with cast iron pipe where wood pipe would be entirely unsatisfactory. It must be admitted that most of the wood pipe companies are coming more to realize these facts, and of late years refuse to furnish pipe where the conditions are unfavorable. Wood pipe is sometimes shipped before needed and left out exposed to harmful weather conditions, causing warping and permitting dirt to get into the stave joints. In some important installations, sap and knotty wood has been used which adds further to its discredit.

In this connection I would call the attention of engineers to some very valuable data on the "Condition of Wood-Stave Pipe on Reclamation Projects," published in the *Engineering News-Record*, March 23, 1922. This article gives the results of 195 installations of wood pipe that have been in service for from five to twenty-five years.

The following are some important points in regard to specifications and conditions:

Pressure. The maximum working pressure to be 200 pounds per square inch, preferably 150 pounds.

Strength of iron and wood. At maximum working pressure the steel bands shall not be subjected to a greater stress than 15,000 pounds per square inch at the weakest section, and the wood shall not be subjected to a greater external pressure than 750 pounds per square inch; preferably 500 pounds, when the round rod has a bearing surface on the wood not to exceed the radius of the rod.

Quality of the wood. Wood may be redwood, fir, white pine, Norway pine or cypress, thoroughly seasoned and before working into staves, air-dried; free from loose or black knots or any knots that pass more than half way through the wood, sap wood, wind shakes, check cracks, dry rot, pitch pockets or pitch seams. For machine spirally banded pipe the gauge of the steel should not be less in thickness than no. 14 BWG except for low pressure: for pipe whose diameters are 8 inches and below no. 18 gauge will be permitted.

The form of the staves and the method of banding shall conform to the manufacturers' standards subject to the approval of the purchaser's engineer or inspector.

All material including the coating shall be inspected before and after fabrication and on the ground when ready to lay, and acceptance is subject to engineers' or inspector's approval.

Storage. After pipe or staves are made, ready for laying, they should be stored in a dry place until ready to be laid.

Leakage. After the pipe is laid, always under the supervision of the manufacturers a test for leakage shall be made under approximately the working pressure for which the pipe is specified. The leakage shall not exceed 700 gallons per 24 hours for each inch of diameter of pipe per mile.

Carrying capacity. While the carrying capacity of wood pipe may be in many cases more favorable, it is recommended that the value of C in Chezy's formula be taken as 110, in which case the formula for flow would be:

$$q = \frac{56{,}000\, d^{\frac{5}{2}} H^{\frac{1}{2}}}{\sqrt{L + 5.87\, d}} \tag{11}$$

in which d = internal diamcter of the pipe in inches.
H = total head available in feet.
L = total length of pipe in feet.
q = flow in gallons per 24 hours.

This formula is suitable for pipe of any length down to about 10 diameters and takes into account the velocity and entrance heads.

The ideal conditions for wood pipe installation are where the pipe is constantly subjected to the pressure from an elevated reservoir and where the pipe is never allowed to become empty except temporarily for repairs or emergency. For pipe covered up in a trench it may not be serious to have it empty occasionally for a week at a time, but were the pipe is exposed in the open air, the sun would likely dry and warp it, so exposed pipe should be kept constantly full of water under material pressure.

Wood pipe should never be laid in cinder fill ground or any place where mine water can reach the bands. Under these conditions with any kind of band or coating other than cement, the bands will rust and break within a very short time.

The same observations would be equally applicable to steel or cast iron pipe.

In conclusion, from our knowledge of the present state of the art of water pipe, it may be stated that the best pipe that could be obtained for any purpose would be cast iron with some sort of a non-corrosive and indestructible inner lining, but, in ten years from now, this statement may be obsolete, and the writer is of the opinion that we are on the eve of great and fundamental improvements in water pipe manufacture.

It is believed, however, that it will be many a decade before the use of wood pipe ceases to be warranted. Wood pipe is in use by at least 500 municipalities and water companies scattered throughout the United States.

In the preparation of this paper I wish to acknowledge my indebtedness to various companies manufacturing wood pipe from whom I have obtained valuable data and discussions. Among the many valuable discussions on this subject I wish to call attention particularly to the splendid paper by Fred C. Scobey on the Flow of Water in Wood Stave Pipe, U. S. Dept. of Agriculture, Bulletin 376.